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Zeolite mineralization of the dacite laccolith of Csódi Hill, Dunabogdány

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Table of contents

1. Introduction

Dunabogdány (called Bogdány previously) is a medium-sized village at the northern foot of Visegrád Mountains, along the right bank of the Szentendre branch of the river Danube. The 279 m Csódi Hill, south of the village has been the site of intensive quarrying for more than 160 years (Fig. 1). The stone has been mostly used for construction and road paving; nowadays it is used as aggregate and for river bank protection. Due to its characteristic garnet phenocrysts and cavity-filling zeolite+calcite hydrothermal assemblage, the rock itself is easy to recognise also among the building stones of the Visegrád Castle, or as the big stone chunks flanking lawns in Budapest (even in the close vicinity of the Eötvös Loránd University Campus, location of the IMA2010 Congress). The hill is a classical mineralogical locality in Hungary. Printed and manuscript field trip guidebooks are witnesses of student field trips for more than a century. The Eötvös Museum of Natural History (Eötvös Loránd University, Budapest, Hungary) has a small exhibition of specimens collected mostly on such field trips. Mineral collectors frequent this locality, too.

Csódi Hill is a typical laccolith, formed 14.8 million years ago in Middle Miocene time, produced in the early volcanic phase of the Börzsöny and Visegrád Mountains (Figs 2–4). The ascending magma was unable to traverse the Oligocene sedimentary strata, but uplifted and burned them. The dark, contact metamorphic slates (Fig. 5) had been exposed along

Csódi Creek previously and are again exposed at the northern side of the quarry due to the intensification of quarrying activity since 2006.

The laccolith is built up of dacite (earlier considered as andesite). The fresh rock is bluish grey, while hydrothermal alteration yielded yellowish brown colour (Fig. 5). The fine-grained matrix contains plagioclase feldspars, biotite, and amphibole. Garnets (almandine) are scattered in the matrix. Xenoliths in the dacite bear a special mineral assemblage formed by the thermal effect of the ascending magma to the enclosed carbonate rock fragments and by later hydrothermal activity. The typical components of the enclaves are brucite, serpentine minerals, hydrogrossular, smectite, and calcite.

Cooling of the laccolith produced characteristic tangential joints and radial fissures. Oldest precipitates on fissure walls are members of a hypothermal paragenesis: overgrown crystals of the rock-forming minerals. However, the mineralogical character of Csódi Hill is determined by the hydrothermal minerals. They include zeolites of worldwide reputation (chabazite-Ca and its twin variety, "phacolite", stilbite-Ca, and analcime). Recently, related to the contact rocks, representatives of the natrolite series were identified, too. Various calcite generations accompany the fissure-filling zeolites. The last precipitates are epigenetic (secondary) minerals, mostly Mn and Fe oxides (hydroxides) (goethite, hematite).

All these minerals were discovered due to the large-scale quarrying since the 1840s. Quarrying flourished during the economic boom of the last third of the 19th century. The first geological descriptions were published by A. Koch – he recognized that the hill is a laccolith. The zeolites and calcite were first reported by J. Szabó, and by F. Schafarzik in the 1870s–1880s. The Csódi Hill analcime, chabazite and stilbite were reported in the classical handbook of Hintze (1897). "Phacolite" is mentioned by the most recent edition of Dana's Mineralogy (Gaines *et al.*, 1997), which lists only the most famous localities.

After the first classical descriptions few data were published for fifty years. R. Reichert and J. Erdélyi were the first to dedicate a detailed study to the zeolites and calcite in 1934. An up-to-date petrographical study was published by Vendl and Takáts in the same year. Méhes (1942) contributed to the geology and stratigraphy. Later the description of hydroantigorite, supposed to be new mineral species by Erdélyi *et al.* (1959), raised further attention of mineralogists. Since then only scattered data were published (Pécsi-Donáth, 1965, on chabazite and stilbite, Passaglia, 1970, on chabazite). Buda (1966) described the rock-forming plagioclases in details, Jánossy *et al.* (1987) revised a zeolite known as globular stilbite to stellerite. Extensive volcanological and geochronological literature was published during a research programme of the Hungarian Geological Institute in the 1970s–1980s (Balla, Balogh, Korpás, Márton-Szalay, *etc.*).

In 1999, an entire monograph was dedicated to the Csódi Hill (Papp, 1999), reviewing earlier geological, petrological, volcanological and mineralogical data, as well as providing new results. The first paper of the monograph (Hála, 1999) reviewed the history of quarrying and stone-masonry in Dunabogdány, while Korpás (1999) the geology and volcanology of Csódi Hill. Harangi (1999) provided new data on petrology

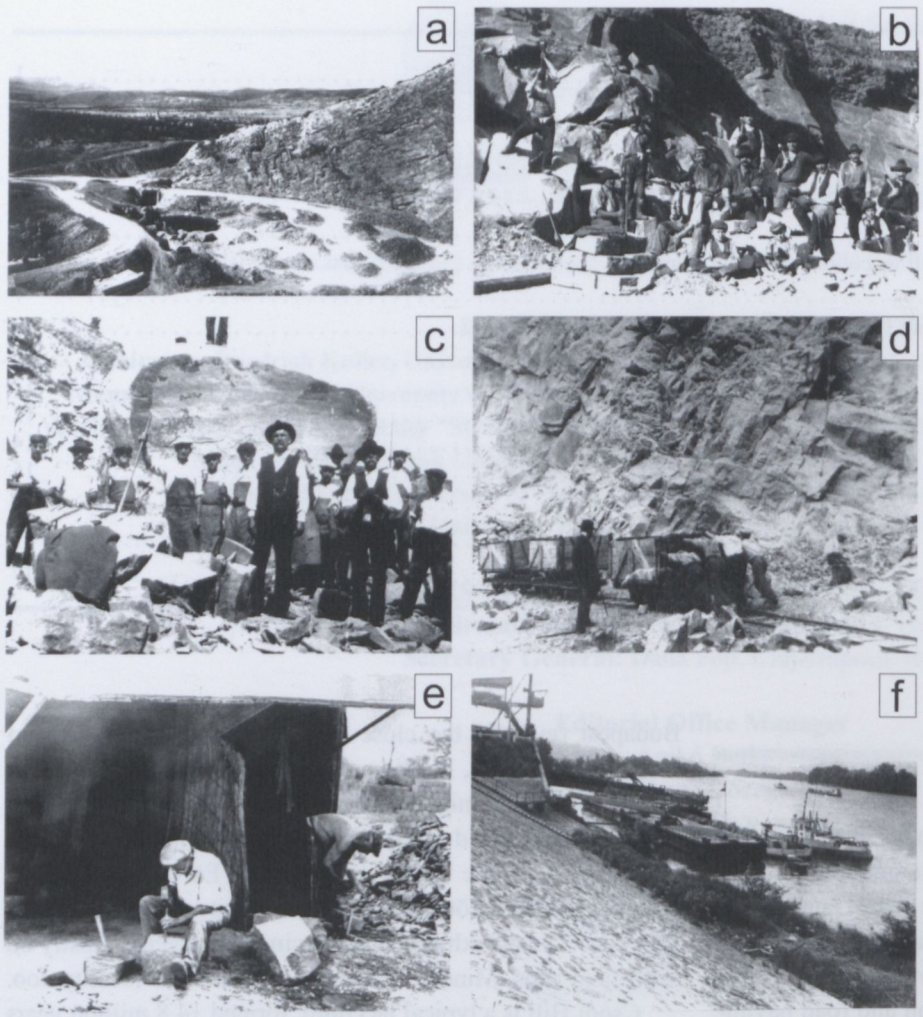

Fig. 1. Scenes from the history of quarrying at Csódi Hill (images taken from Hála, 1999). a – Alsóbánya (= Lower Quarry) in 1912 (photo: Scherf, E.). b – Stonecutters in the mid 1920s (reproduction: Hála, J.). c – A group of quarrymen in 1939 (reproduction: Mrs. Pellérdy). d – Wagons are pushed to the loading place in 1939 (reproduction: Mrs. Pellérdy). e – Stonecutting: kerbstone making in the early 1960s (reproduction: Mrs. Pellérdy). f – New loading station on the bank of the Danube with a loading tow-boat in the early 1970s (reproduction: Hála, J.).

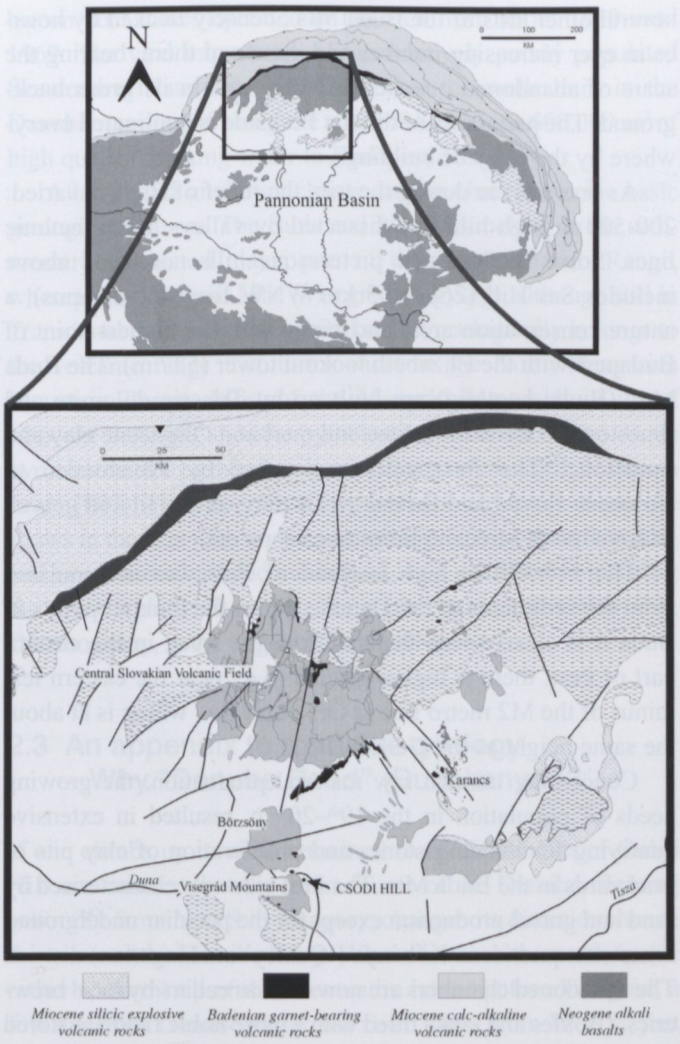

Fig. 2. Csódi Hill at the western segment of the Neogene Carpathian calc-alkaline volcanic arc (Harangi, 1999).

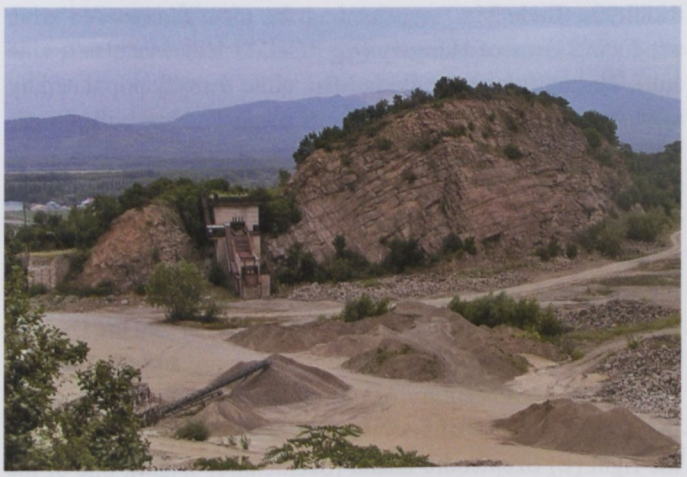

Fig. 3. View of the quarry from the upper level. Photo: Kugler, A.

and geochemistry. One of the major steps forward was the recognition of the laccolith as dacite instead of andesite. A paper on rock-forming garnets (Szabó *et al.,* 1999) was followed by the mineralogical articles proper. Mineral assemblages were presented in the order of decreasing temperature.

Fig. 4. Fresh (grey) and hydrothermally altered (yellowish brown) dacite (photo: Fehér, B).

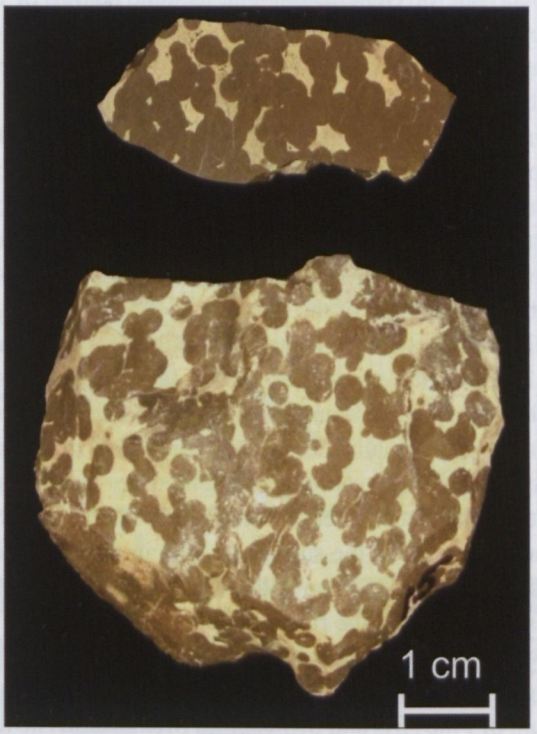

Fig. 5. Contact metamorphic spotted slate, hand specimen (below) and cut surface (above; photo: Orosz, E.), varieties with smaller spot size exist, too.

First the serpentine-bearing xenoliths (Papp & Szakáll, 1999, and a separate paper on "hydroantigorite", Papp *et al.,* 1999), then the less known hypothermal minerals were described (Szakáll & Kovács, 1999). Numerous new data were given on zeolites (Tóth *et al.,* 1999) and calcite (Fekete *et al.,* 1999). Finally, a paper was dedicated to iron saponite (Weiszburg *et al.,* 1999), a special clay mineral associated with zeolites. This field guide, having only one geological stop, the Csódi Hill, is mainly based on the above mentioned monograph, as well as on the field guide of Papp *et al.* (1999). New results, published here, are all related to the re-found contact metamorphic spotted slates, the first results on which were compiled in the framework of a master thesis. Additional analyses on the newly found acicular zeolite, appearing in the cracks of the spotted slate were produced by Jánosi, M.

2. A sketchy roadside geology

2.1 General features

The field trip reaches Dunabogdány along route 11 (see the map on the back cover), which roughly follows the course of the Danube. To the left one can enjoy a hilly panorama whereas until the Danube Bend the nearly flat margin of the Great Hungarian Plain is to be seen (with the low foothills of the northern mountains in the distance) to the right. This is a consequence of a major tectonic line, the presence of which is indicated even to those unfamiliar with geology by the steep Danubian side of Gellért Hill. The tectonic setting of the hill was exploited in a rather unfriendly manner by pagan Hungarians during their last revolt in 1046, when Gerhardus (980–1046), Italian-born Bishop of Csanád, captivated by the pagan rebels at the ferry of Pest, was pushed to the Danube from the top of the hill. The hill was then renamed after Gerhardus (Gellért in Hungarian), who was canonized in 1083 together with Stephen I, first king of Hungary, and his son Prince Imre, of whom Gerhardus was tutor. Hotel (and Spa) Gellért is located at the southern feet of the hill.

This fault system is sometimes called as "thermal fault line", as thermal waters feeding the famous Budapest spas upwell by the Danube along this fault line (some 120 springs). The carrier of thermal water are karstified Mesozoic sedimentary rocks (platform carbonates), sometimes up to 3 km in thickness, with intercalated fissured marly-cherty facies rocks. They are exposed on the surface as hills in the Buda side (W from the river) but less than 4 km distance from the Danube in the Pest side (E from the river), they were hit only by a 970 m deep well. This well was drilled in 1868–1878, it is used for the feeding of Széchenyi Spa near Hősök tere (Heroes' Sq., with Museum of Fine Arts and Millennium Memorial). The temperature of the springs in Buda is between 25–60 °C, while the temperature of the thermal water of Széchenyi bath is 73–76 °C. Uplifted parts of the karstified rocks are of course free from thermal water but their empty place, *i.e.,* the spectacular caves with 50 km explored length, is another geological peculiarity of Budapest. As a matter of course, these are rather thermal karst caves with hydrothermal minerals (barite, calcite, fluorite, gypsum, cinnabar, *etc.*) than "normal" dripstone caves.

2.2 Brief itinerary

The starting point of the trip is the Riverside (Lágymányos) Campus of the University on the Buda side of the Hungarian capital. It was built on a landfilled area, originally a floodplain of the Danube, similar to the lower parts of the other, Pest side. The route then follows the E feet of the Buda Mts., passing by Gellért Hill (235 m) at the Danube and Castle Hill (Vár-hegy), site of the mediaeval town of Buda (168 m), and further on by several other hills of the Buda Mts., densely flecked by houses in ever increasing number and, here and there, bearing the scars of abandoned quarries and clay pits in its green background. The panorama of the flat Pest side is dominated everywhere by the mass of buildings.

As one can see during the trip, the relief of Buda is varied: 200-500 m high hills are dissected by valleys along tectonic lines. Some of the more picturesque hills not listed above includes Sas Hill (266 m, 3 km WNW from the campus), a nature conservation area, and János Hill, the highest point of Budapest with the Elizabeth lookout tower (527 m). The Buda Mts. (Budai-hegység) are built up by Triassic dolomite and limestone, Eocene limestone and marl and Oligocene clay and sandstone. The Pest side is covered by Pleistocene to Holocene fluvial and fluvial-aeolic clay, silt, sand and gravel. In some parts Miocene limestone crops out.

The 110-120 m high lowland of Pest was accumulated from the sediments of the Danube. From the lookout points in Buda it is clearly seen that far from the river, in the eastern part of Pest, there is higher ground (*e.g.,* near the eastern terminus of the M2 metro line at Örs vezér Sq., which is at about the same height as the Gellért Hill).

Concerning mineral raw material production, the growing needs of population in the 19th–20th c. resulted in extensive quarrying for building stones and proliferation of clay pits of brickyards in the Buda Mts. The Pest side was characterised by sand and gravel production except for the peculiar underground limestone quarries in Kőbánya ('Quarry' in Hungarian) district. The abandoned chambers are now used as cellars by local breweries. (Bottles and tanks filled with a more noble fluid are stored in cavities of similar quarries on the Buda side at Budafok, centre of the Hungarian champagne manufacturing.) It is to be noted here that until the devastating "phylloxera plague" of the 1880-90s, Buda Mts. were among the most famous red wine producing areas of Hungary (*e.g.,* Gellért Hill was also a vine hill). The settling of the Buda Mts., quite densely populated by now, started after the "phylloxera plague" when villas were "planted" on the place of the ruined vineyards.

The ruins of the town and military base of Aquincum (capital of the Roman province Pannonia) are located in Óbuda ("Old Buda", now part of Budapest). The ruins, on both side of the road, and the partly reconstructed remains of the Roman aqueduct between the lanes remind the traveller that the Danube served as frontier between the Roman Empire and the "barbarians" in the 1st–4th century AD. After leaving Óbuda until reaching Pomáz, the hills of the Pilis Mts. emerge to our left (W). To the right (E) Szentendre Island (Szentendrei-sziget), one of the largest Danube island (length 31 km, area 56 km^2) stretches just till the Danube Bend. The route follows the river branch Szentendrei-Duna, the main branch of the Danube is on the other side of the island. Pilis Mts. are built up mainly by Triassic (dolomite and limestone) and Eocene to Oligocene sedimentary formations (clay and sandstone). In addition to quarrying of raw materials for building and construction industry, small-scale

brown coal mines operated in the area from about 1850 until 1969. The vital importance of the relatively poorly populated Szentendre Island lies in the fact that the wells built in the Danubian sediment along the riverbank produce 600,000 m^3 of high quality drinking water to Budapest every day.

After Pomáz an abrupt change can be observed in the basic geological features. The Buda and Pilis Mts. belong to the sedimentary-dominated major part of the Transdanubian Range, whereas the Visegrád Mts. (Visegrádi-hegység), although still in Transdanubia in the geographical sense, geologically belongs to the volcanic range that forms most of the North Hungarian Mountain Range. Most of the Visegrád Mts. is built up of Miocene andesite, andesite pyroclastite, some dacite and dacite pyroclastite (for further details see Harangi *et al.*, 2001; Karátson *et al.*, 2007). There are only a few economically insignificant ore shows in the area with no historic mining activity, therefore mineral raw material production is (and was) restricted to quarries; the most significant among them, the quarry on Csódi Hill, Dunabogdány, is the target of the trip (Fig. 6).

2.3 An appendix to roadside geology – Why "Danube Bend" (Dunakanyar)?

If one climbs up to what remained from the summit of Csódi Hill one can see that the main course of the Danube, flowing generally from N to S in Hungary, changes its direction, hence the name of the Danube Bend. When we reach the northern (or rather western) tip of the Szentendre Island before Visegrád, a few km from Dunabogdány, the river flows from W to E, just like when it enters to Hungary at Szob, some 8 km westward. Between these two points the river takes a U-shaped turn, forming perhaps the most spectacular part of the Danube Bend. Visegrád Castle, on the Várhegy (Castle Hill) overlooks this fine panorama. According to Karátson *et al.* (2006) the shape of this U-turn is the consequence of inherited volcanic forms (caldera, lava domes) exhumated by the incision of the Danube during the emergence of the Visegrád and Börzsöny Mts. and the simultaneous subsidence of the Little and Great Hungarian Plain. Due to this still active process, lasting since the Pleistocene, the Danube carved a 200-300 m deep valley with a series of fluvial terraces.

3. Field stop: Csódi Hill, Quarry

Location: To the south of the village Dunabogdány, GPS coordinates: 47.778574 N, 19.037097 E.

Keywords: Laccolith formation, garnet-bearing dacite, serpentine-bearing enclaves, contact metamorphism, hydrothermal mineralisation

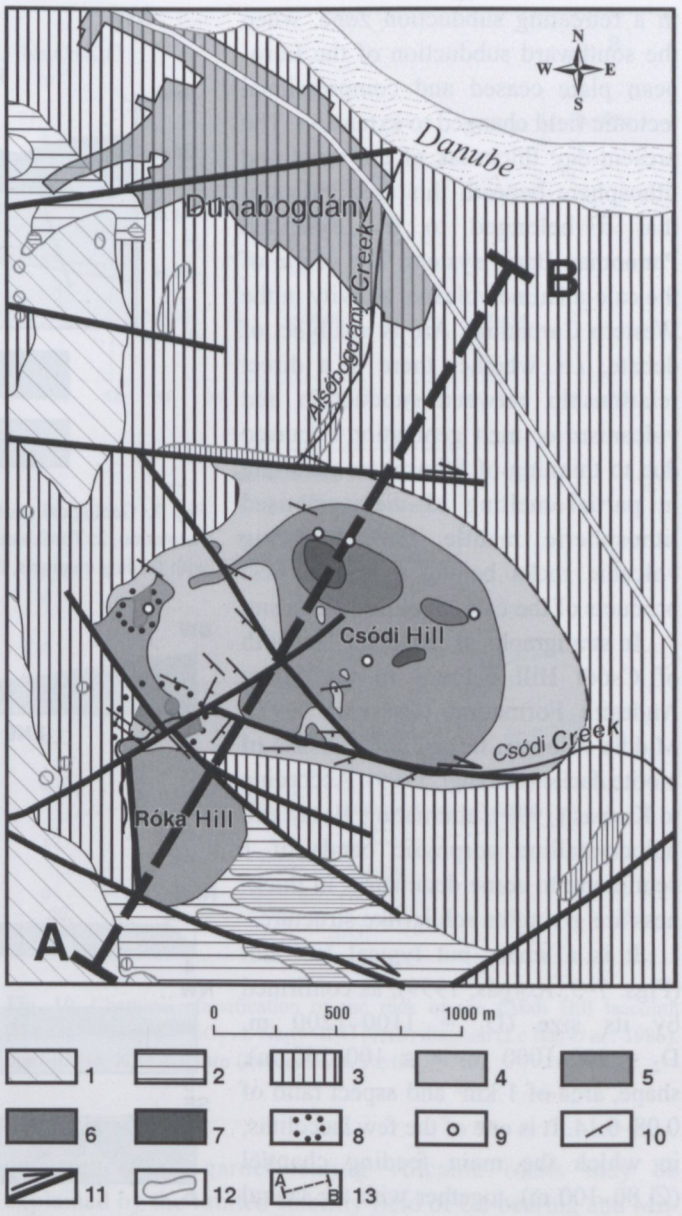

Fig. 6. Geological map of Csódi Hill and its surroundings, without Quaternary formations (Korpás, 1999). Legend: 1: Mátra Andesite Formation, 2: Budafok Formation, 3: Törökbálint Sandstone Formation, 4: Kiscell Clay Formation, 5: Amphibole-biotite dacite laccolith, 6: Crater, 7: Feeding channel, 8: Covered feeding channel, 9: Late feeding channel, 10: Dip of strata, 11: Fault and dextral fault, 12: Outcrop and observation point, 13: Geological section.

3.1 Geological background of the Csódi Hill laccolith and its surroundings

The Middle Miocene subvolcanic rocks of Csódi Hill belong to the andesite-rhyodacite volcanic complex of the Visegrád Mts (for a comprehensive overview see Karátson *et al.*, 2000). They formed between 14 and 16 Ma as a part of widespread Middle Miocene to Quaternary calc-alkaline volcanism along the northern and eastern part of the Pannonian Basin (Fig. 3, Harangi, 1999). The calc-alkaline volcanism at the western segment of the Carpathian volcanic arc occurred

in a retreating subduction zone, when the southward subduction of the European plate ceased and compressional tectonic field changed to extension. The present-day thickness of the crust and lithosphere beneath this area indicates that it belonged to the extended Pannonian Basin system. The origin of the calc-alkaline volcanic activity in the Western Carpathian Arc is a subject of debate, *i.e.* whether there is a direct relationship between subduction and volcanism or melt generation occurred due to thinning of lithosphere resulting in partial melting of metasomatised lithospheric mantle. Garnet-bearing volcanic rocks belong to the earliest products of the calc-alkaline volcanism.

In stratigraphical sense, the laccolith of Csódi Hill belongs to the Mátra Andesite Formation (Császár, 1997), Middle Miocene in age and consists of biotite dacite (Harangi, 1999). According to Korpás (1999), alternating glassy and holocrystalline porphyric bands of 1 centimetre to some decimetres in thickness are giving its schlierlike structure.

It is a small, but typical laccolith (Figs. 7–9; Korpás, 1999), as confirmed by its size (D_1 = 1100–1200 m, D_2 = 900–1000 m, A ≅ 100–150 m), shape, area of 1 km² and aspect ratio of 0.08–0.14. It is one of the few laccoliths, in which the main feeding channel (∅ 80–100 m), together with the lateral (∅ 50–100 m) and the peripherial late ones (∅ 2–5 m) are excellently exposed (Fig. 8, Korpás, 1999). The laccolith intruded along the boundary of the Kiscell Clay and Törökbálint Sandstone Formation and resulted in the formation of a contact-metamorphic zone, less than 4 m in thickness. The proportion of phenocrysts in the less viscose fluidal dacite is about 22–23%. The maximum thickness of sediments overlying the laccolith was 450 m at the time of intrusion. The early (sill development) stage of the laccolith is not yet exposed. The following (bending) stage is known only in some of the profiles. The third (cupola development) stage with its central and lateral feeding channels is represented by wonderful profiles (Fig. 8., Korpás, 1999).

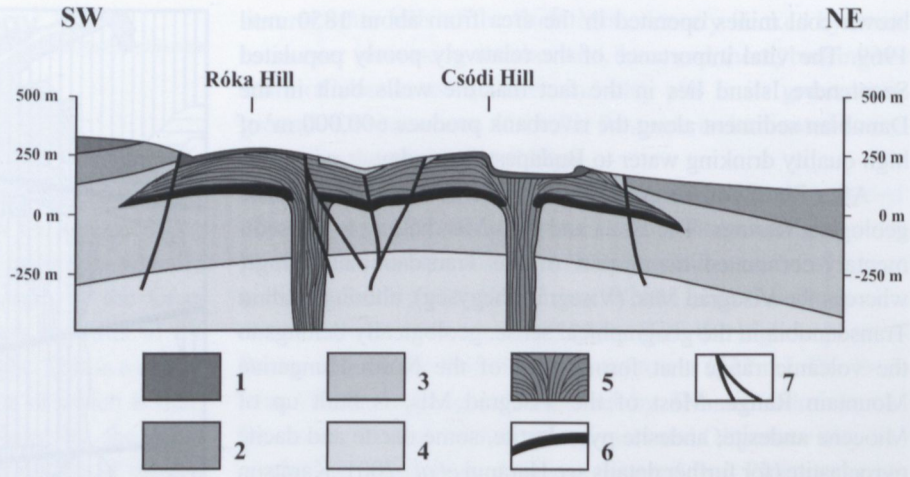

Fig. 7. Geological profile of Csódi Hill and Róka Hill (Korpás, 1999). Legend: 1: Mátra Andesite Formation, 2: Törökbálint Sandstone Formation, 3: Kiscell Clay Formation, 4: Lower Sand, 5: Laccolith with feeding channels, 6: Sill, 7: Fault.

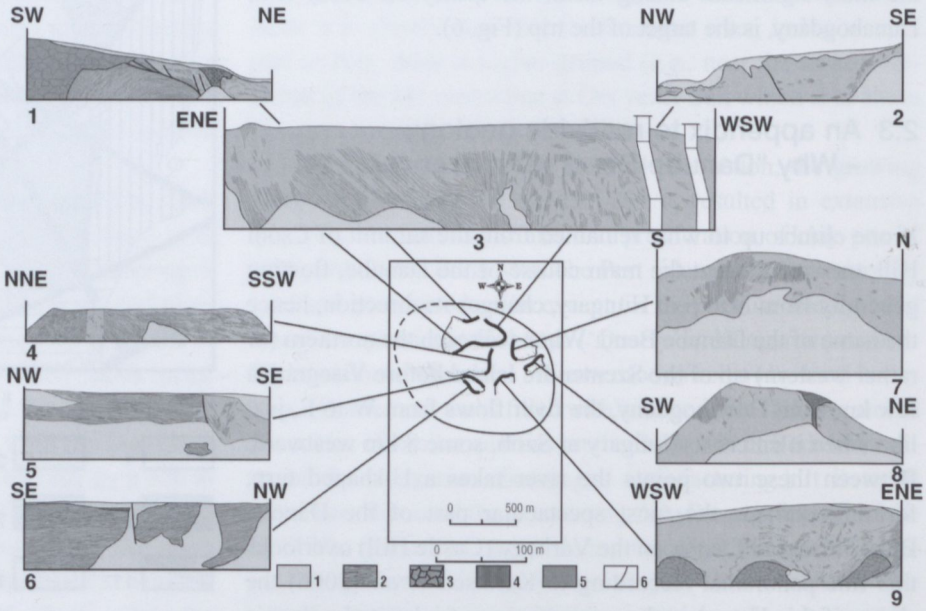

Fig. 8. The laccolith of Csódi Hill and its detailed sections as seen on the quarry walls (Korpás, 1999). Legend: 1: Area covered by soil and debris, 2: Fluidal banded dacite, 3: Blocky dacite, 4: Contact metamorphic clay, 5 Late feeding channels and breccias, 6: Fault.

The peripherial channels of the final (kink development) stage penetrated through the uncompletely solidified laccolith. The laccolith of Csódi Hill was fed, beside its central channel in NE, by at least two independent lateral channels, too. These independent feeding channels have been joined only below 2 km depth. The laccolith is a single shallow intrusion with scarce xenoliths coming from the pre-Tertiary carbonate basement and showing typical contact metasomatic mineral association. The banded structure indicates a continuous, rhytmic and fractional crystallisation, driven by changes in pressure.

The central feeding channel (∅ 300 m) of the similar, but less exposed Róka Hill laccolith (Fig. 7) is covered mainly by sediments. Both laccoliths formed in a dextral shear zone from WSW to ENE and nice examples of ductile deformation can be studied in the quarries of Csódi Hill. The axis of the asymmetric ellipsoidal central and lateral feeding channels should correspond to the conjugated Riedel faults of this shear zone. In the saddle between

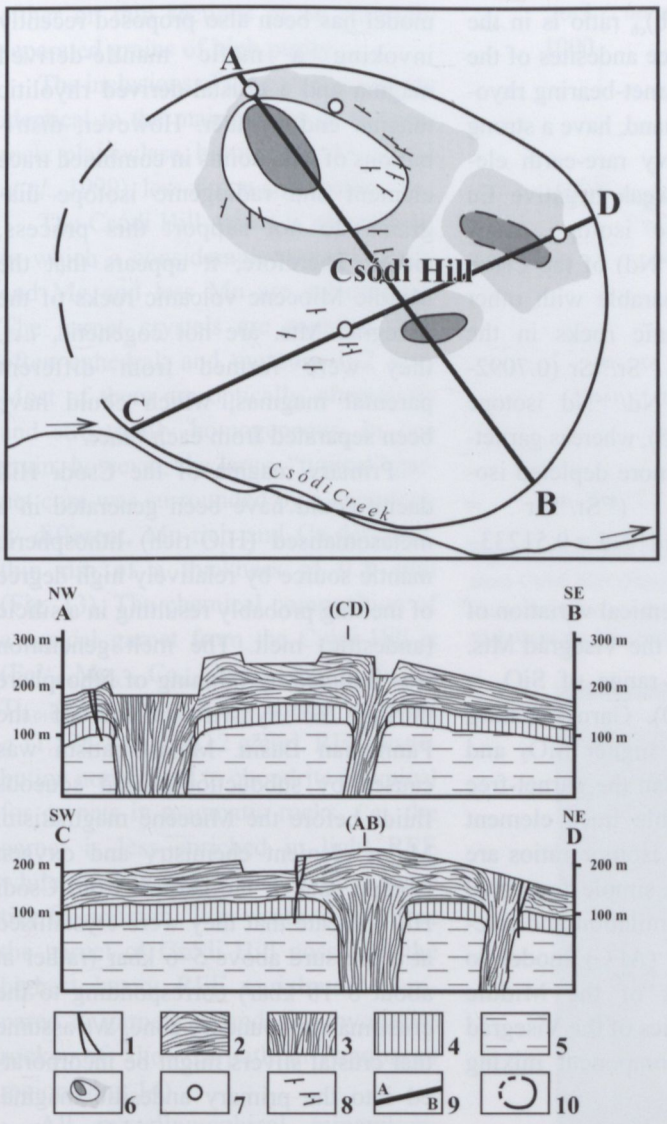

Fig. 9. Architecture and typical sections of the Csódi Hill laccolith (Korpás, 1999). Legend: 1: Late feeding channels of the kink development stage, 2: Mantle of the cupola and bending development stages, 3: Feeding channels, 4: Sill, 5: Kiscell Clay, 6: Crater and cone-mantle of the individual feeding channels, 7: Late feeding channels, 8: Dip, 9: Geological section, 10: Contour of the laccolith.

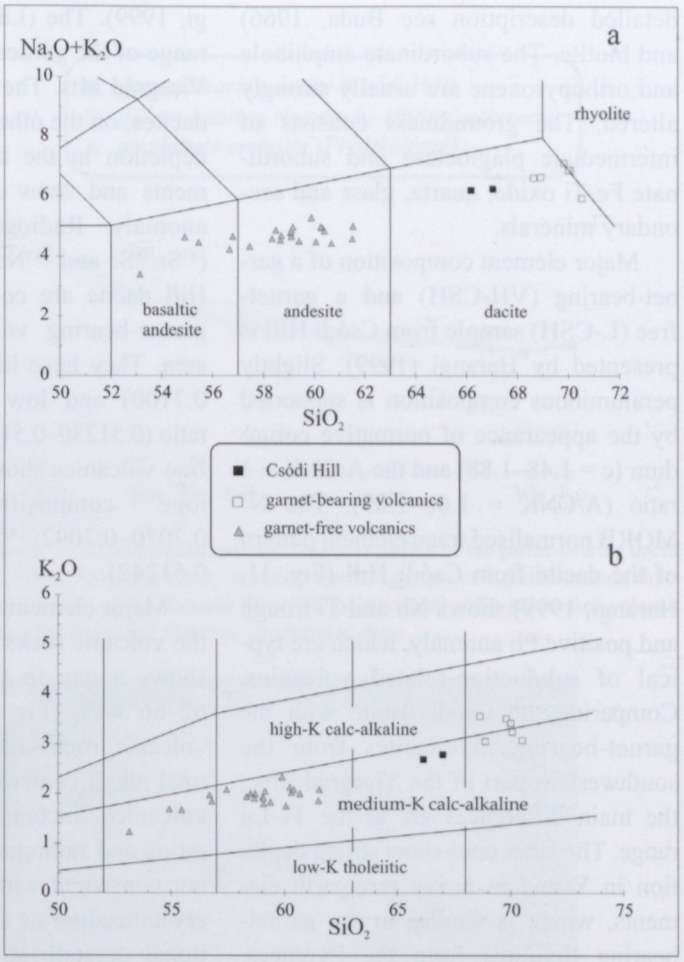

Fig. 10. Chemical classification of the rock of the Csódi Hill laccolith (Harangi, 1999). a – SiO_2 *vs.* Na_2O+K_2O (TAS) diagram (Le Bas *et al.,* 1986). b – SiO_2 *vs.* K_2O diagram (Peccerillo & Taylor, 1976).

the domes of Csódi Hill and Róka Hill laccoliths the area collapsed and a syntectonic graben of NW–SE direction formed.

Balogh & Árva-Sós (1978) reported 16.1±1.0 Ma K/Ar radiometric age for the Csódi Hill laccolith, while Korpás *et al.* (1998) and Korpás (1999) suggested that it formed at the end of the early volcanic phase, about 14.8 Ma ago. Its rhythmic growth is represented by overburden slices of some centimetres and decimetres in thickness and the duration is estimated to be less than 10 Ky (Korpás, 1999).

3.2 Petrology of the Csódi Hill dacite

Garnet-bearing volcanic rocks are rare world-wide and only limited data are available about them (Harangi, 1999). Rare occurrences of garnet-bearing volcanic rocks may be explained by the limited stability field of Ca-bearing and Mn-poor almandine garnets (Green, 1977, 1982). Experimental studies pointed out that they can crystallise from H_2O-rich silicic magma at high pressure (8–12 kbar). Preservation of euhedral garnet phenocrysts implies rapid ascent of the host magmas. Almandine garnets are usually hosted by peraluminous (S-type) SiO_2-rich volcanic rocks, which are derived by anatexis of granulite facies metapelitic lower crustal rocks. On the other hand, there are many examples of diopside-normative (I-type) garnet-bearing volcanic rocks, which were formed from mantle-derived magmas.

The volcanic rock of Csódi Hill is classified as medium-K garnet-bearing biotite-dacite (Fig. 10, Harangi, 1999). Phenocrysts are of max. few mm in size, according to Kósa (1998), plagioclase is the most frequent (50–60 vol%), followed by biotite (20–30 vol%), some pyroxene (5–15 vol%), amphibole (5–10 vol%) and garnet (up to 5 vol%). Garnets (Alm = 65–70%, Gro = 9–14%, Szabó *et al.,* 1999) are primary phenocrysts, *i.e.* they crystallised from the magma. They are coexisting with calcic plagioclase (An = 77–86%, for a

detailed description see Buda, 1966) and biotite. The subordinate amphibole and orthopyroxene are usually strongly altered. The groundmass consists of intermediate plagioclase and subordinate Fe-Ti oxide, quartz, glass and secondary minerals.

Major element composition of a garnet-bearing (VH-CSH) and a garnet-free (L-CSH) sample from Csódi Hill is presented by Harangi (1999). Slightly peraluminous composition is supported by the appearance of normative corundum (c = 1.48–1.88) and the A/CNK > 1 ratio (A/CNK = 1.06–1.09). The N-MORB normalised trace element pattern of the dacite from Csódi Hill (Fig. 11, Harangi, 1999) shows Nb and Ti trough and positive Pb anomaly, which are typical of subduction-related volcanics. Comparing the Csódi dacite with the garnet-bearing rhyodacites from the southwestern part of the Visegrád Mts., the main differences are at the Ti–Lu range. The latter ones show strong depletion in Y and in heavy rare-earth elements, which is similar to the garnet-bearing rhyolites from the Pyrenees. Chondrite-normalised rare-earth element pattern of the Csódi dacite is smooth without any Eu-anomaly (Fig 12, Harangi, 1999). The $(La/Yb)_{ch}$ ratio is in the range of the garnet-free andesites of the Visegrád Mts. The garnet-bearing rhyodacites, on the other hand, have a strong depletion in the heavy rare-earth elements and show a weak negative Eu anomaly. Radiogenic isotope ratios ($^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$) of the Csódi Hill dacite are comparable with other garnet-bearing volcanic rocks in the area. They have high $^{87}Sr/^{86}Sr$ (0.7092-0.7100) and low $^{143}Nd/^{144}Nd$ isotope ratio (0.51230–0.51235), whereas garnet-free volcanics show more depleted isotope composition ($^{87}Sr/^{86}Sr$ = 0.7070–0.7092; $^{143}Nd/^{144}Nd$ = 0.51233–0.51242).

Major element chemical variation of the volcanic rocks of the Visegrád Mts. shows a gap in the range of SiO_2 = 62–66 wt% (Fig. 10). Garnet-bearing volcanic rocks have higher SiO_2 and total alkali content than the garnet-free volcanics. Incompatible trace element ratios and radiogenic isotope ratios are not consistent with a simple fractional crystallisation or assimilation and fractional crystallisation (AFC) model to explain the genesis of the Middle Miocene volcanic series of the Visegrád Mountains. A two-component mixing model has been also proposed recently invoking a mafic mantle-derived magma and a crustal-derived rhyolitic magma end-member. However, distributions of data points in combined trace element and radiogenic isotope diagrams do not support this process, either. Therefore, it appears that the Middle Miocene volcanic rocks of the Visegrád Mts. are not cogenetic, *i.e.*, they were formed from different parental magmas, which could have been separated from each other.

Primary magma of the Csódi Hill dacite could have been generated in a metasomatised (H_2O-rich) lithospheric mantle source by relatively high degree of melting probably resulting in a silicic (andesitic) melt. The melt generation was initiated by thinning of lithosphere during the syn-rift period of the Pannonian Basin. Metasomatism was caused by subduction-related aqueous fluids before the Miocene magmatism. Major element chemistry and oxygen isotope data of the garnets from Csódi Hill indicate that they were crystallised at a pressure above 5–6 kbar (rather at about 8–10 kbar) corresponding to the crust-mantle boundary zone. We assume that crustal slivers might be incorporated into the primary andesitic magma, resulting in an increase of Al_2O_3 content. This allowed the high pressure crystallisation of garnet along with calcic plagioclase. Since the euhedral garnet phenocrysts are well preserved and the host rock does not show negative Eu-anomaly, the Csódi Hill dacite could have been formed from only a slightly differentiated melt that ascended relatively fast to the surface. High-pressure garnet and plagioclase fractionation could have resulted in a more differentiated magma from which the garnet-bearing rhyodacites were generated.

Szabó *et al.* (1999) examined the relationship of the Csódi Hill garnet to the host rock along with the garnet's inclusions and paragenesis. They determined the crystallographic and crystal chemical characteristics of garnet and as well as its rare earth element (REE) pattern. The examinations were carried out

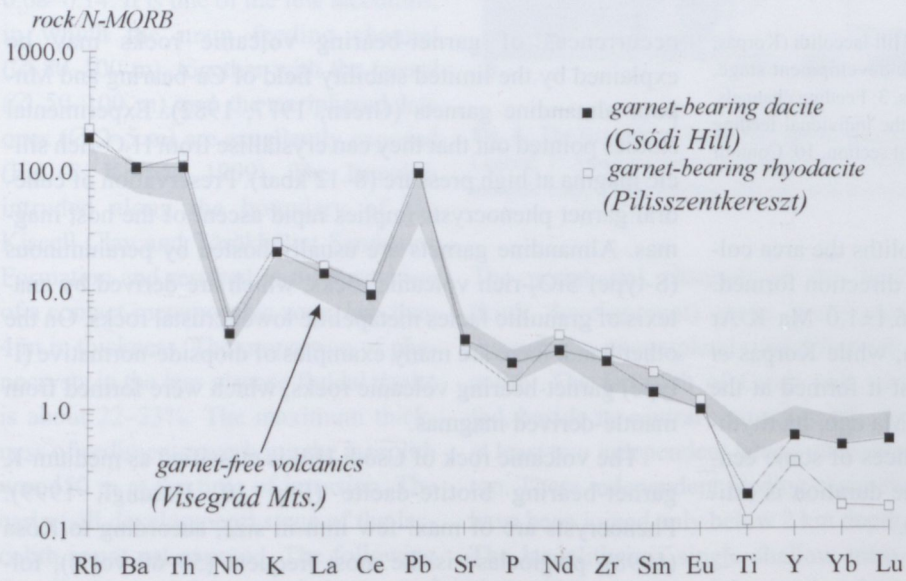

Fig. 11. N-MORB (Pearce & Parkinson, 1993) normalised trace element pattern of the garnet-bearing dacite from Csódi Hill (filled squares; Harangi, 1999). For comparison, trace element pattern of a garnet-bearing rhyodacite from the southwestern margin of the Visegrád Mts. (Pilisszentkereszt, open squares) and the field of garnet-free volcanic rocks from the Visegrád Mts. are also presented (Harangi, unpublished data).

either on thin sections or on carefully separated grains of high purity.

The inclusions of the garnet grains are identical to the main phases of the host rock: plagioclase, biotite (Fig. 13, Szabó *et al.,* 1999), less zircon and apatite.

The Csódi Hill garnet is ***almandine,*** in which a considerable amount of Ca and Mg and less Mn are substituting. The garnet crystals are rounded, less often euhedral, and measure 1–2 mm. Most of them are optically, chemically and structurally homogeneous. In one grain, however, the large, "typical" garnet core was surrounded by a chemically different, Mn-rich and Ca-deficient, thin rim of a thickness of 0.X mm (Fig. 13). The chemical composition of a typical garnet from the Csódi Hill is $(Fe^{2+}_{2.015}Mg_{0.381}Ca_{0.410}Mn_{0.185})(Al_{1.955}Fe^{3+}_{0.041}Ti_{0.019})(Si_{2.984}Al_{0.016})O_{12}$, lattice constant a 11.576 Å, ρ_{calc} 4.12 g/cm^3. REE distribution normalised to chondrite is typical for garnets in magmatic rocks, *i.e.,* the garnet is less enriched in light REE while more in heavy REE, with a negative Eu anomaly. It is worth to note that the garnet of Csódi Hill possesses the highest heavy REE enrichment compared to garnets of andesite-rhyodacite rocks of the Carpathian-Pannonian region (Fig. 14).

All crystallographical, mineralogical, petrological and geochemical results support the primary magmatic origin of the garnet. Crystallization occurred at a pressure of 8–10 kbar and at a temperature of 850–900 °C (Fig. 15, Szabó *et al.,* 1999).

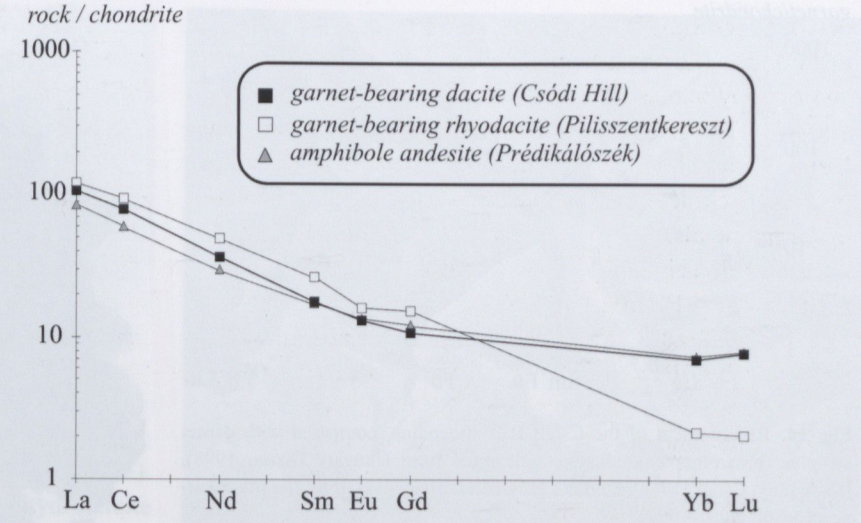

Fig. 12. Chondrite (Nakamura, 1974) normalised rare-earth element pattern of the garnet-bearing dacite from Csódi Hill (Harangi, 1999). For comparison, rare-earth element pattern of a garnet-bearing rhyodacite from the southwestern margin of the Visegrád Mts. (Pilisszentkereszt) and a garnet-free volcanic rock from the Visegrád Mts. (Prédikálószék; Harangi, unpublished data).

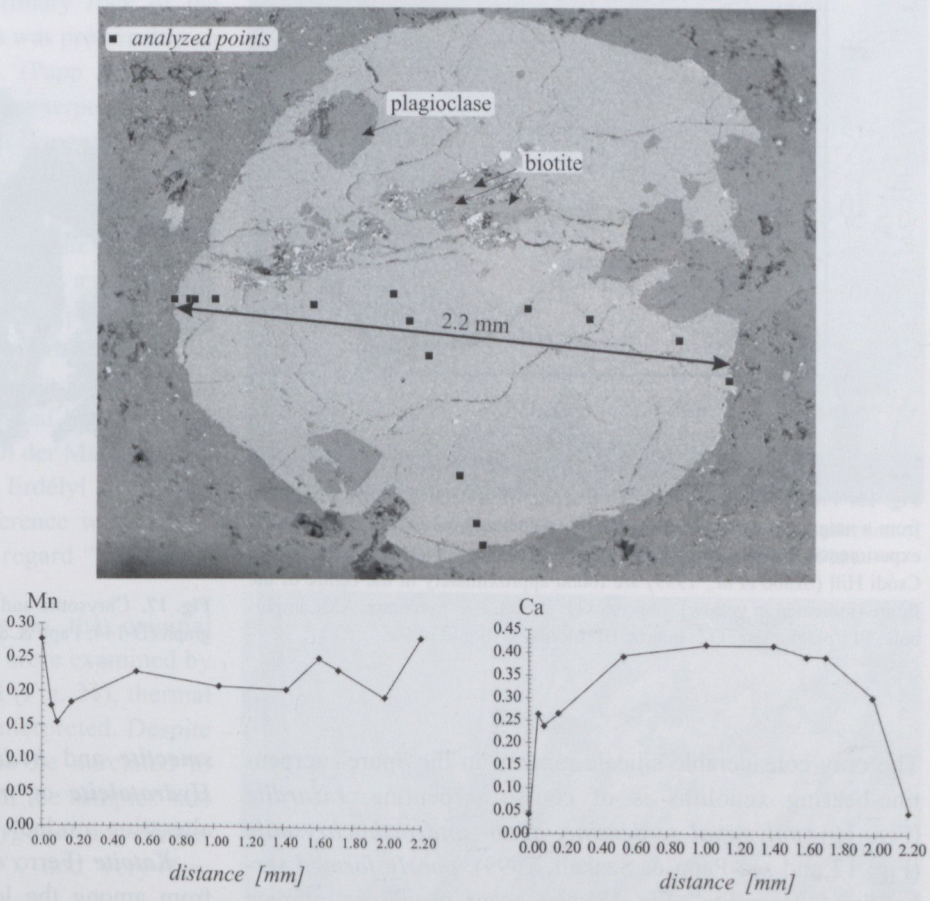

Fig. 13. Zoned almandine crystal (back scattered electron image, Szabó *et al.,* 1999). Dots indicate the microprobe measurements. Below: Distribution of Mn and Ca (*a.p.f.u.*) along the traverse marked on the figure.

3.3 Serpentine-bearing xenoliths in the Csódi Hill dacite

Serpentine-bearing xenoliths from the dacite laccolith of Csódi Hill were first studied by Erdélyi *et al.* (1959). A revision of the museum samples and new collecting by Papp & Szakáll (1999) led to the recognition of several types of enclaves. The most abundant ones are those described by Erdélyi *et al.* (1959): massive, white or pale tinted microcrystalline materials ("pure" serpentine-bearing xenoliths) and previously unknown, light coloured (white to yellowish), more or less porous, frequently hydrogrossular-bearing xenoliths. Other types with different texture but similar mineral composition are also found sometimes.

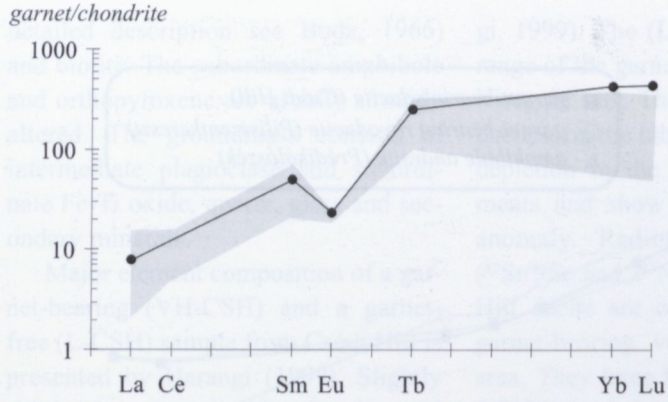

Fig. 14. REE content of the Csódi Hill almandine, compared with garnet samples from other calc-alkaline volcanites from Hungary (Kósa, 1998). Black dots: Csódi Hill almandine, grey band: area covered by the other garnets (Szabó *et al.,* 1999).

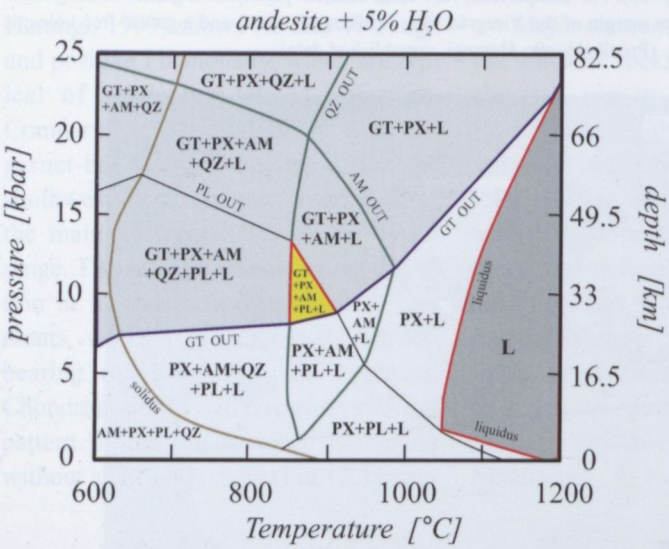

Fig. 15. Pressure-temperature (PT) diagram of mineral phases crystallizing from a magma of andesitic composition (containing 5 % H_2O), based on the experimental data of Green (1982). The field of the coexisting minerals of the Csódi Hill (Szabó *et al.,* 1999) are found approximately in the centre of the figure (indicated in yellow). Legend: GT: garnet, PX: pyroxene, AM: amphibole, PL: plagioclase, QZ: quartz, BI: biotite, L: liquid phase.

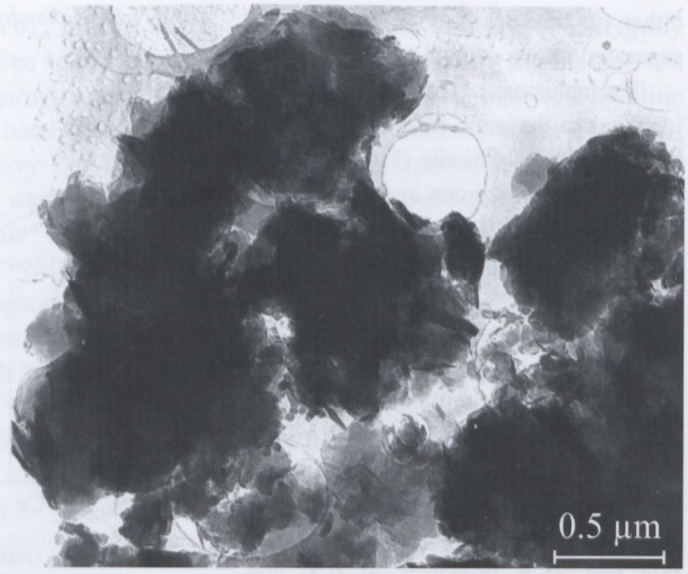

Fig. 16. Lizardite, xenomorphic flakes. TEM micrograph (D-139, Papp & Szakáll, 1999).

Fig. 17. Chrysotile and polygonal serpentine (thicker "rods"). TEM micrograph (D-144; Papp & Szakáll, 1999).

The only considerable silicate mineral in the "pure" serpentine-bearing xenoliths is of course serpentine. ***Lizardite*** (Fig. 16), ***polygonal serpentine***, ***clino- and orthochrysotile*** (Fig. 17 and see Papp & Szakáll, 1999), ***poorly formed serpentine*** ("deweylite", Fig. 18) also occur, usually as intimate mixtures. ***Calcite*** is the dominant accompanying mineral, ***brucite*** may also prevail in some samples. There is no proof of the presence of "sheridanite" and "magnesium-chamosite" mentioned by Erdélyi *et al.* (1959), the assumed hydromagnesite has not been detected, either.

In the other xenoliths serpentine minerals (predominantly lizardite, frequently multi-layer polytypes) and calcite still exist as main components. However, a dioctahedral ***smectite*** and ***hydrogrossular*** may also be predominant. ***Hydrotalcite*** or ***manasseite*** (Fig. 19) is a characteristic alteration product.

Katoite (Ferro *et al.,* 2003; Fig. 20) is to be highlighted from among the less known minerals of the contact zone between the xenoliths and the enclosing dacite.

The mineral paragenesis of the xenoliths has been formed in several phases. The rock fragments detached from the sedimentary basement (Korpás, 1999) by the ascending magma underwent a thermal metamorphism first. This "primary" paragenesis was transformed by hydrothermal fluids circulating in the cooling and solidifying volcanite. This phase produced most of the minerals actually found in the enclaves (brucite,

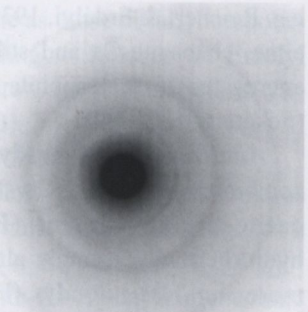

Fig. 18. "Deweylite", SAED pattern showing continuous diffuse rings (D-69B; Papp & Szakáll, 1999).

serpentine, hydrogrossular, smectite, a part of calcite). "Deweylite" with ***aragonite***, a part of calcite and hydrotalcite (manasseite?) is bound to the late hydrothermal phase.

The paragenetical differences of the two main xenolith types can be attributed to the differences in the primary rock: "pure" serpentine-bearing enclaves have been formed from almost "pure" dolomite, whereas the primary rock of the hydrogrossular- and smectite-bearing ones was presumably an Al- and Si-containing (marly) dolomite. (Papp & Szakáll, 1999) lists the mineral paragenesis of similar serpentine-bearing xenoliths found in volcanic rocks from Hungary.

Papp *et al.* (1999) re-examined "hydroantigorite", which was described as a new mineral species by Erdélyi *et al.* (1959) from a brucite-serpentine xenolith of the Csódi Hill near Dunabogdány. It was originally defined as a monoclinic (*a* 5.23, *b* 9.17, *c* 14.48 Å, β 91.45°, *P*2/*m*?) serpentine, characterised by an OH for O substitution in the tetrahedral layer. Its structural formula was given as $(Mg_{2.584}Fe^{2+}_{0.012}Mn_{0.02}Al_{0.016}Fe^{3+}_{0.009})Si_2O_{4.811}(OH)_{4.189}$. Further data were published by Veniale & van der Marel (1963), Beutelspacher & van der Marel (1968), van der Marel & Beutelspacher (1976), Erdélyi & Veniale (1970) and Veniale (1972). Standard reference works (*e.g.*, Strunz & Tennyson, 1982; Clark, 1993) regard "hydroantigorite" as antigorite with some OH excess.

Topotype specimens corresponding to the original description given by Erdélyi *et al.* (1959) were examined by Papp *et al.* (1999) by optical, XPD, TEM (Fig. 21), thermal and IR methods and earlier data were reinterpreted. Despite of its name, "hydroantigorite" proved to be unrelated to antigorite, and the dominant component of the samples was found to be ***orthochrysotile*** and some ***polygonal serpentine***, ***poorly formed serpentine*** ("deweylite"), and very few ***lizardite***.

No direct evidence was found for the supposed OH for O substitution. The residual OH content of the heated sample, observed in the 500–700 °C temperature range (Erdélyi & Veniale, 1970; Veniale, 1972), can be attributed to a transitional phase formed during thermal decomposition. The deviation of the chemical composition of "hydroantigorite" from the theoretical values may be explained by "deweylite" admixture.

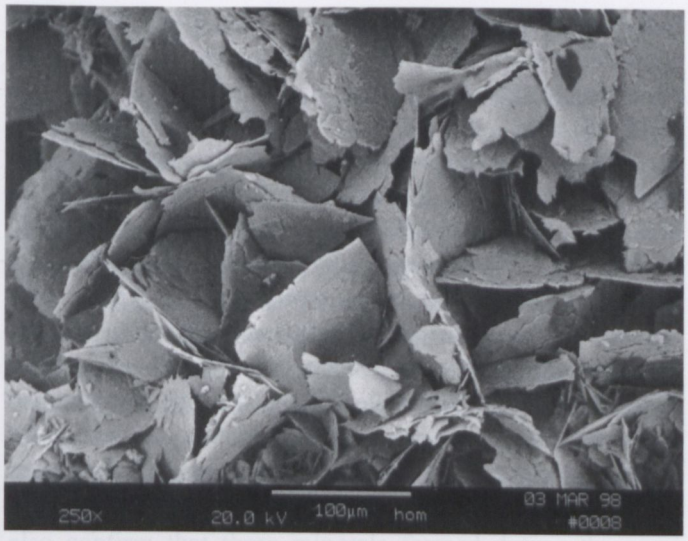

Fig. 19. Hydrotalcite (manasseite?), lamellar crystals. SEM micrograph: Kovács, Á. (collection of the Herman Ottó Museum, Miskolc, Hungary; Papp & Szakáll, 1999).

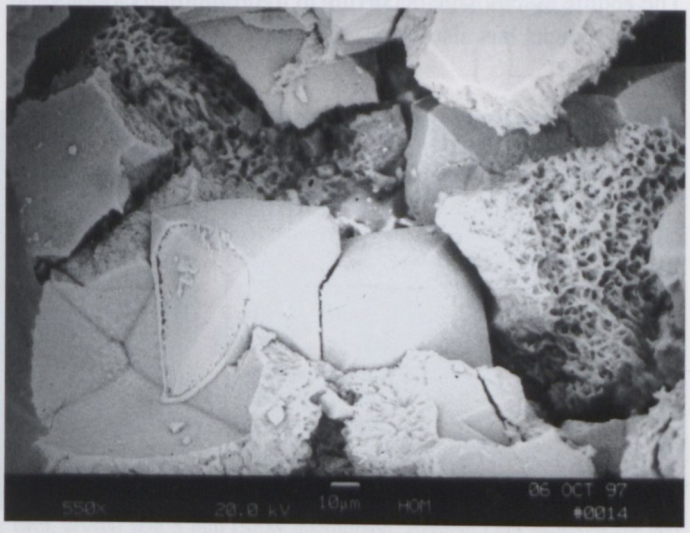

Fig. 20. Crystals of katoite. SEM micrograph by Kovács, Á. (collection of the Herman Ottó Museum, Miskolc, Hungary; Papp & Szakáll, 1999).

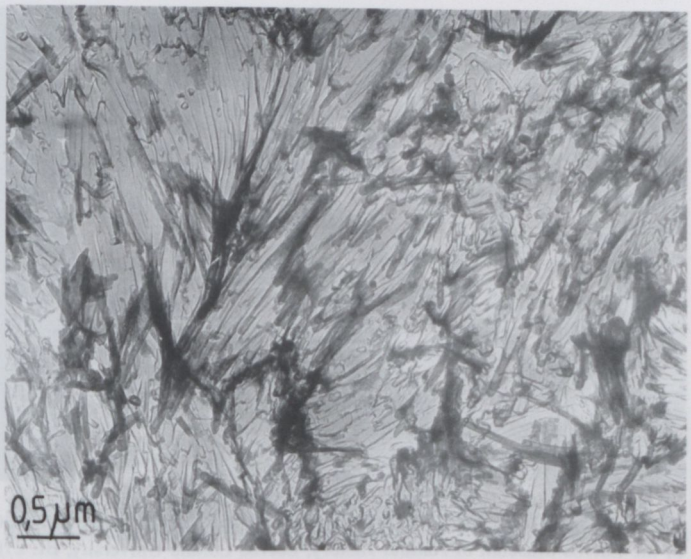

Fig. 21. Surface TEM replica micrograph of "hydroantigorite" (Papp *et al.*, 1999).

3.4 Cavity-filling minerals

3.4.1 Hypothermal minerals

Hypothermal ("pneumatolytic") minerals were the first to crystallise in the cavities of the Csódi Hill dacite. According to Szakáll & Kovács (1999), they include ***apatite*** (Fig. 22a), ***quartz*** (Fig. 22b), ***magnetite***, ***zircon***, ***ilmenite***, ***monacite-(Ce)***, ***hornblende***, ***plagioclase*** and ***sanidine***, all as microscopic crystals (up to 1 mm). This paragenesis practically corresponds to the rock-forming minerals. Ubiquitous but small ***pyrite*** crystals (Fig. 22c) formed shortly after, followed by the hydrothermal assemblage (zeolites, calcite and saponite) and lastly, the supergene minerals (iron and manganese oxides). Pyrite has often been altered to ***goethite***.

3.4.2 Hydrothermal zeolites

The zeolite assemblage occurring in hydrothermal cavities and cooling cracks has also been well known for a long time (see *e.g.* Reichert & Erdélyi, 1935). The paragenesis includes analcime, chabazite-Ca and stilbite-Ca accompanied by tubular aggregates of iron saponite and several generations of calcite (Fekete *et al.*, 1999).

Analcime occurs mostly as 1–3 mm sized crystals, {211} combined with {100}. Crystals on the unaltered "bluish-grey" dacite are transparent (Fig. 23b), while those on the hydrothermally strongly altered "yellowish-brown" rock are more or less cloudy (Fig. 23a). General formula is $Na_{0.9}[Al_{0.9-1.0}Si_{2.0-2.1}O_6]\cdot 9–13H_2O$). Optical properties – $2V_D$ 20(2)°, α_D 1.4860(3), β_D 1.4866(3), γ_D 1.4868(3) – and TEM SAED patterns suggest that analcime is orthorhombic (*Immm*, *I*222 or *Imm*2); calculated unit cell parameters are as follows: *a* 13.737(3), *b* 13.747(6), *c* 13.705(1) Å.

Chabazite-Ca appears both as "phacolite" twins (see the cover image and Fig. 24a–b) and as rhombohedra (Fig. 24c). The crystals vary widely in colour, transparency (colourless transparent, cloudy white and pink), and size (rhombohedral crystal edges in the mm-1.5 cm range). Average chemical formula is $Ca_{1.1-1.5}Na_{0.3-1.3}K_{0.1-0.2}[Al_{3.3-3.6}Si_{8.5-8.7}O_{24}]\cdot 13–15.2H_2O$). Optical

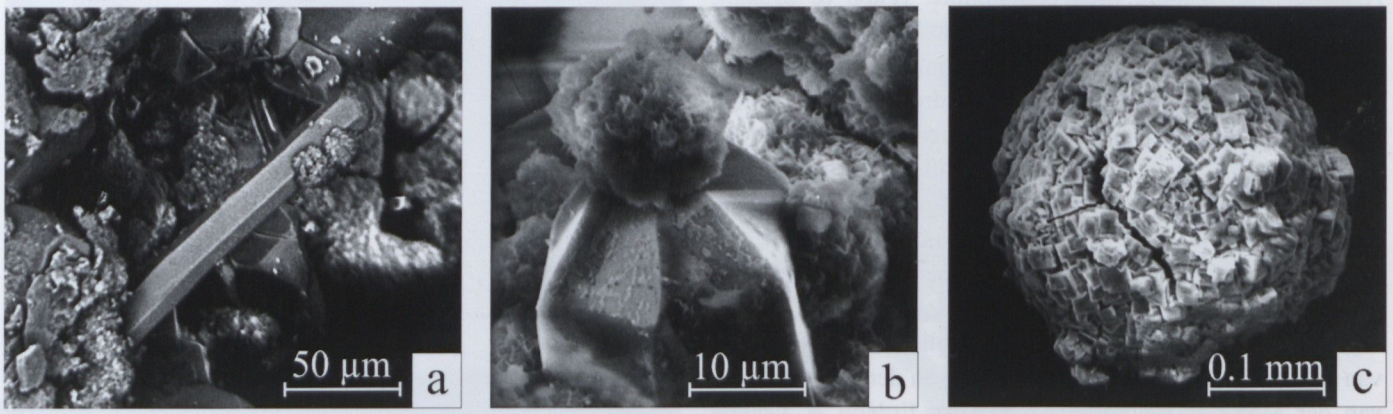

Fig. 22. Hypothermal minerals of the Csódi Hill dacite cavities (SEM micrographs; Szakáll & Kovács, 1999). a - Apatite, needle-like crystal. b - quartz with saponite "cap". c - Pyrite, globular aggregate of hexahedral crystals altered into limonite (collection of the Hungarian Natural History Museum, Á.72.99.).

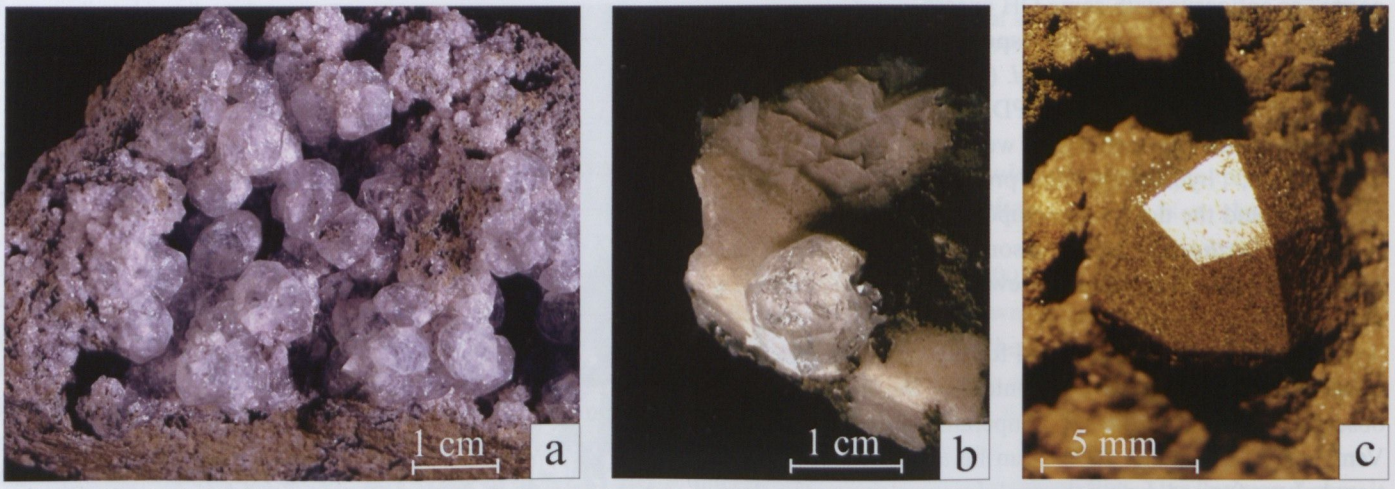

Fig. 23. Cavity-filling analcime crystals (Tóth *et al.*, 1999). a – Analcime, cloudy crystals (6–8 mm in diameter) on hydrothermally altered dacite (collection of the Eötvös Museum of Natural History, Eötvös Loránd University, BE 21642; photo: Kulcsár, G.). b – Clear analcime crystal on lamellar calcite ("paper spar") (Herman Ottó Museum collection, HOM 22659; photo: Kulcsár, G.). c – Analcime deltoidicositetrahedron tinted greenish by a web of iron saponite inclusions (Hungarian Natural History Museum collection, Á.70.396; photo: Papp, G.).

properties of phacolite are the same as those of the rhombohedral crystals, n_D 1.485(2) according to Reichert & Erdélyi (1934, 1935). The studied chabazite-Ca crystal is triclinic ($P\bar{1}$, unit cell parameters are: *a* 9.405(3), *b* 9.406(2), *c* 9.435(3) Å, α 94°28.2±1', β 93°48.2±1', γ 94°39.0±1'.

Stilbite-Ca occurs as pale yellow tabular crystals and as sheaf-like (Fig. 25a) or radial-globular aggregates (Fig. 25b). Average formula is $Ca_{4.0-4.2}Na_{1.3-1.7}K_{0-0.2}[Al_{9.7-9.8}Si_{26.2}O_{72}] \cdot 29.0–33.5H_2O$). The studied stilbite-Ca crystal is monoclinic (*C*2/*m*), unit cell parameters are: *a* 13.634(2), *b* 18.212(2), *c* 11.282(1) Å, β 127°50±50'.

The XPD pattern of the spheroidal zeolite formerly identified as stellerite (Jánossy *et al.*, 1987) shows strong evidence of monoclinity, so this morphological variety is also stilbite-Ca (no presence of stellerite has been proved so far among the zeolites of Csódi Hill).

Zeolites of Csódi Hill are products of hydrothermal activity. Hydrothermal cavities can be filled with zeolites only (1), zeolites and different generations of calcite (2) or zeolites and iron saponite (3). Iron saponite often occurs as inclusion in zeolites (cover image and Fig. 23c). Several zeolite generations are assumed. The first one – small, transparent analcime and chabazite-Ca crystals – is widespread in the neighbouring area as well (Visegrád Mountains, Southern Börzsöny Mountains). The second generation – zeolites showing great variability both in form and colour – is characteristic only for Csódi Hill. The succession trend proposed by Reichert & Erdélyi (1935), *i.e.* chabazite-Ca (incl. phacolite) – analcime – stilbite-Ca, was proved with strongly overlapping crystallisation periods. Chabazite-Ca can be both older and younger than analcime, but stilbite-Ca is always the youngest zeolite. Calcite formed during the whole zeolite crystallisation period, while iron saponite is connected only to the late stage of crystallisation. Stable isotope data of calcite (Fekete *et al.*, 1999) and analcime (Demény *et al.*, 1997) also confirm that these minerals formed during the same crystallisation period. Calcite and iron saponite accompanying the zeolites never appear in the same cavity, which may be a result of completely different genetic circumstances.

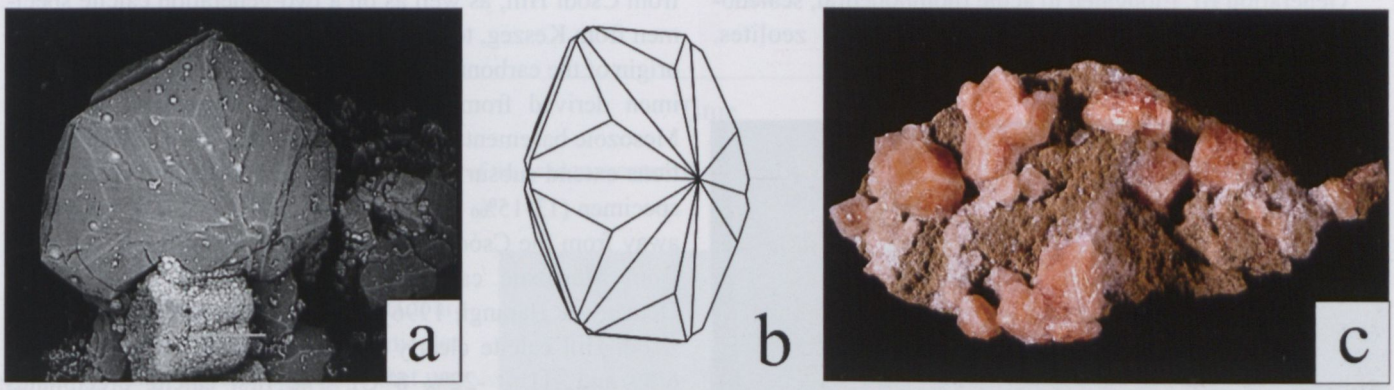

Fig. 24. Cavity-filling chabazite-Ca from Csódi Hill. a – Chabazite, phacolite twin, crystal size 5 mm (SEM micrograph, Herman Ottó Museum (HOM), Miskolc, Tóth *et al.*, 1999). b – idealised drawing of the phacolite crystal (drawn by Fehér, B.; HOM, Miskolc, Tóth *et al.*, 1999). c – Typical pink rhombohedra of chabazite, picture width 45 mm (HOM collection, Miskolc, photo: Kulcsár, G.).

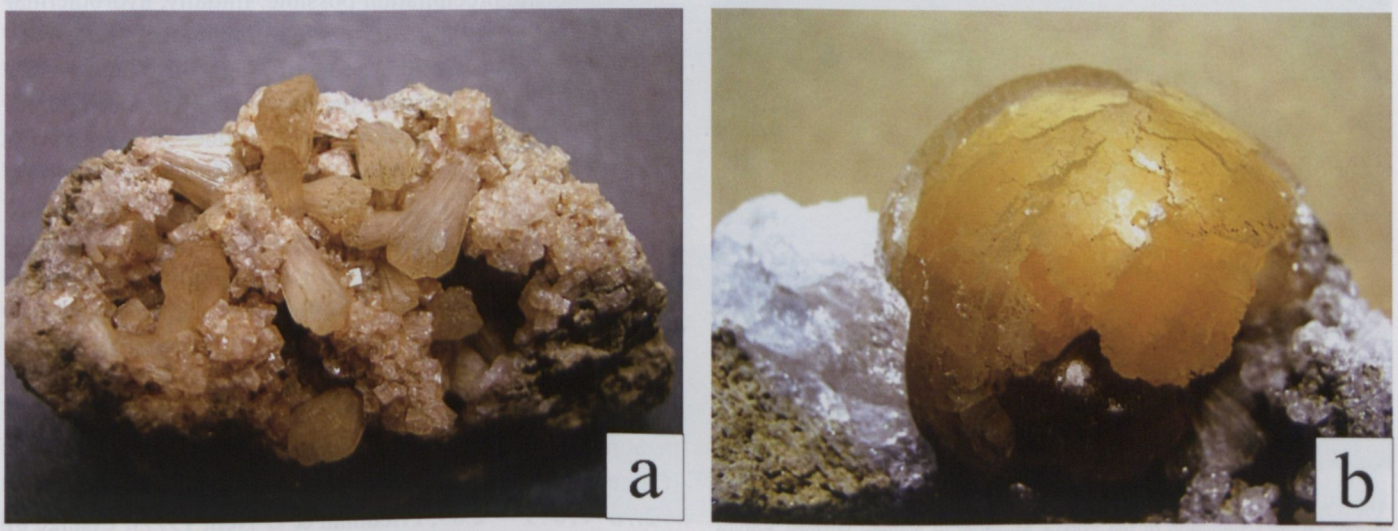

Fig. 25. Cavity-filling stilbite-Ca from Csódi Hill. a – Sheaf-like aggregates of stilbite on pink chabazite crust. (Herman Ottó Museum collection, HOM 26008; photo: Szakáll, S.). b – Globular stilbite, diameter of the aggregate: 30 mm. Photo and collection: Tibor Horváth.

3.4.3 Hydrothermal calcite

A characteristic member of the mineral paragenesis of Csódi Hill is ***calcite,*** occurring in fissures and cavities of the dacite. Szabó (1871) was the first to recognise calcite here, and Reichert & Erdélyi (1934, 1935) were the last to describe it. Fekete *et al.* (1999) contributed substantially to the knowledge of the morphology and formation of the Csódi Hill calcite.

Fekete *et al.* (1999) studied 31 samples by stereomicroscope, scanning electron microscopy and reflection goniometer, and distinguished four generations related to zeolites.

Generation "0". Massive, white calcite without zeolites – probably predates zeolites, suggested by stable isotope composition.

Generation I and II. Specimens are usually lamellar, tabular according to (0001). Crystallisation of Generation I calcite preceded zeolites, and is always associated with late zeolite mineralisation (Fig. 23b). Generation II calcite is contemporaneous with the zeolites. Thin parallel lamellae ~ 0.X mm distance apart are grown between analcime or chabazite (Fig. 26).

Generation III. Elongated to acute rhombohedral, scalenohedral crystals. Their crystallisation followed zeolites. Variable morphology allowed further subdivision: Group III/a. ochre yellow, always steep, approx. $\{02\bar{2}1\}$ and $\{07\bar{7}2\}$ rhombohedra, isolated or as core of "octahedral" (Group III/b) crystals. Group III/b. Colourless, transparent crystals, 5–10 mm in length. $\{02\bar{2}1\}$ rhombohedron is always combined with the basal planes. A few specimens bear narrow prismatic faces. Those crystals with well-developed basal planes resemble regular octahedra. Group III/c. $\{07\bar{7}2\}$ rhombohedron is combined with prism faces. Group III/d. Larger, yellow or grey rhombohedra, 5–20 mm in size. Group III/e. Tiny, acute, clear crystals of 1–5 mm length. $\{02\bar{2}1\}$ or $\{07\bar{7}2\}$ rhombohedra, combined with $\{11.9.\bar{2}0.2\}$ and even steeper scalenohedra.

Fig. 26. Calcite ("paper spar") with chabazite-Ca crust, width of the crystal group: 10 cm (collection of the Eötvös Museum of Natural History, Eötvös Loránd University, B20437; photo: Király, J.).

X-ray powder diffraction study revealed no impurities or any deviation from usual calcite cell values.

Seven samples were studied by optical emission spectrophotometry. OES results also supported the low trace element content of the samples: 0.1–1% Mn, 0.X% Fe and Mn, 6–8 ppm Be and 1–10 ppm Sr was found. 0.X% Si, Al, and Na is probably from accompanying zeolites.

Stable isotope studies were made on 16 calcite specimens from Csódi Hill, as well as on a two-generation calcite specimen from Keszeg, to understand the genesis of calcite and the origin of the carbonate (Fekete *et al.,* 1999). The Keszeg specimen derived from a sedimentary environment, from the Mesozoic basement blocks in the Danube Bend. These formations extend subsurface as far as the Csódi Hill. The Keszeg specimen (13-15‰ $\delta^{18}O$ and -2-+0.5 ‰ $\delta^{13}C$) is definitely far away from the Csódi Hill fields; its carbonate was mobilised from Mesozoic carbonate rocks (Demény *et al.*, 1994, Demény & Harangi, 1996). The carbonate component of the Csódi Hill calcite clearly indicates igneous origin (17-23‰ $\delta^{18}O$ and -11 – -22‰ $\delta^{13}C$). The first calcite precipitates (Generations 0, I, and III/a) are closely related to the early stage of laccolith formation, when the magma domed up the overlying organic-rich Oligocene strata. The departing CO_2 made carbonate precipitation possible. Initially, hydrothermal fluids were heavily mixed with intraformational water containing organic matter oxidized in the igneous contact zone (Generations 0 and I). Later the mixing ceased and terminal calcite displays only hydrothermal influence (Generation III/a). The post-zeolite calcite – *i.e.* most of the cavity-filling paragenesis of Csódi Hill (Generations III/b-e) – displays pure hydrothermal origin. Its formation is due to the outgassing contemporaneous with cooling. Outgassing – departure of CO_2 – occurred within the solid laccolith, due to minor, secondary fissure formation (Korpás, 1999). Isotope data show, that assuming ~ 250 °C initial crystallisation temperature, the cooling of the system is characterised by a 100 °C drop in temperature, and the main mineralisation occurred around 150 °C. (Calculations were made with the equation $\delta^{18}O_{calcite} - \delta^{18}O_{fluid} = 2.78 \times 10^6/T^2 - 2.89$; Friedman & O'Neil, 1977). Change of calcite morphology during the mineralisation process is illustrated by Fig. 27.

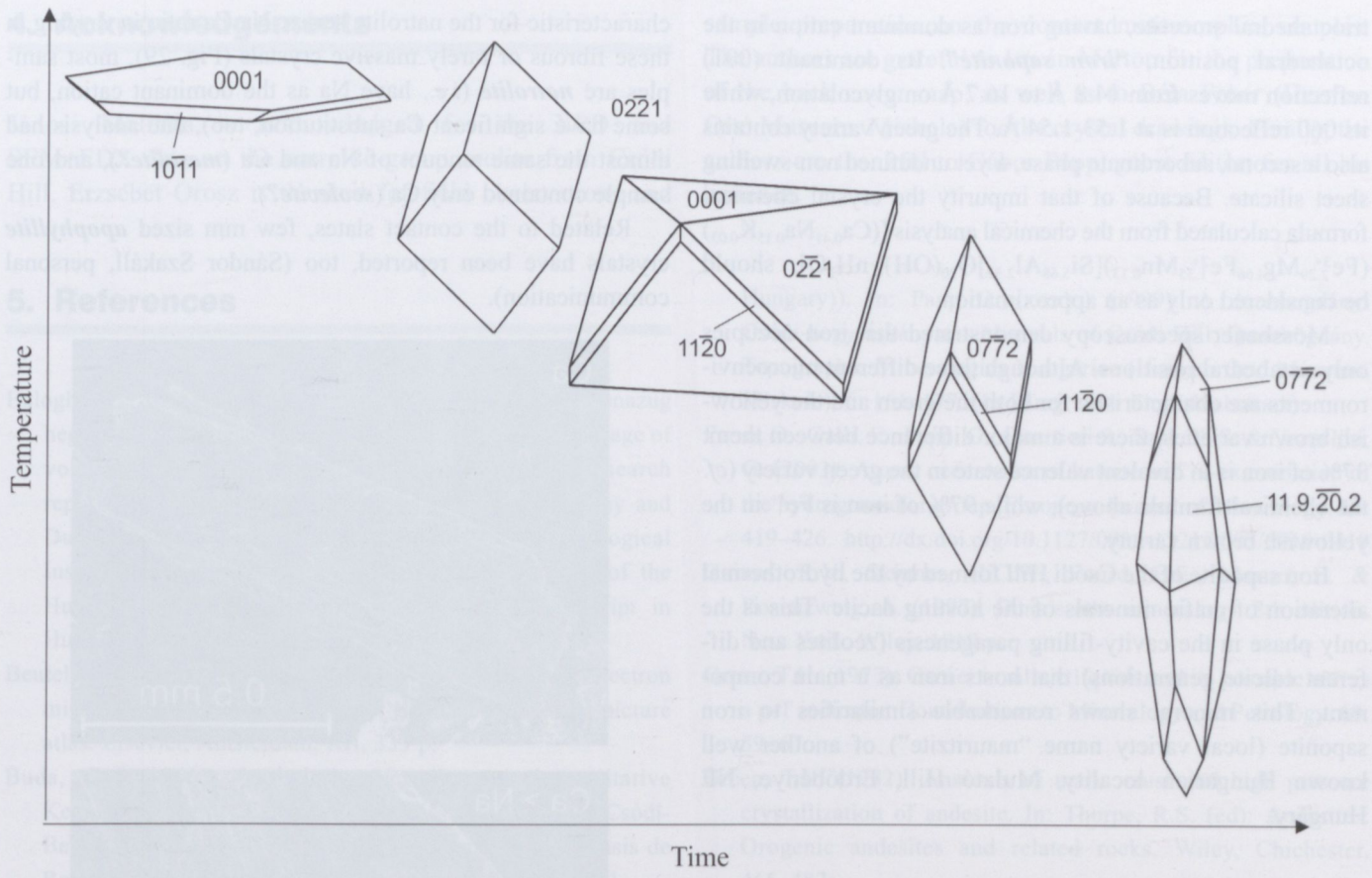

Fig. 27. Crystal morphology of calcite as a function of time and temperature (Fekete *et al.*, 1999).

3.4.4 Hydrothermal saponite

The cavity filling zeolites of Csódi Hill are sometimes accompanied by a vermicular, cylindrical clay mineral aggregate that was first studied by Weiszburg *et al.* (1999). The cylindrical or tubular aggregates are always to be found in cavities hosting zeolites. It may form inclusions in larger phacolite (cover image) and untwinned chabazite crystals, or less often in analcime (Fig. 23c) or in stilbite. It may also grow on the surface of these zeolites. In some cases it can be found as loose networks in the cavities. This clay mineral can never be found in cavities hosting also calcite. The cylinders/tubes are of a diameter of 30-50 μm, their maximum length is 4-500 μm (Fig. 28). Two colour varieties, a darker green (Fig. 23c) and a brighter yellowish brown one (cover image) are characteristic for that clay mineral. Unfortunately, in the recently quarryied parts, it is not available.

Both chemical and X-ray powder diffraction data suggest that the mineral is a

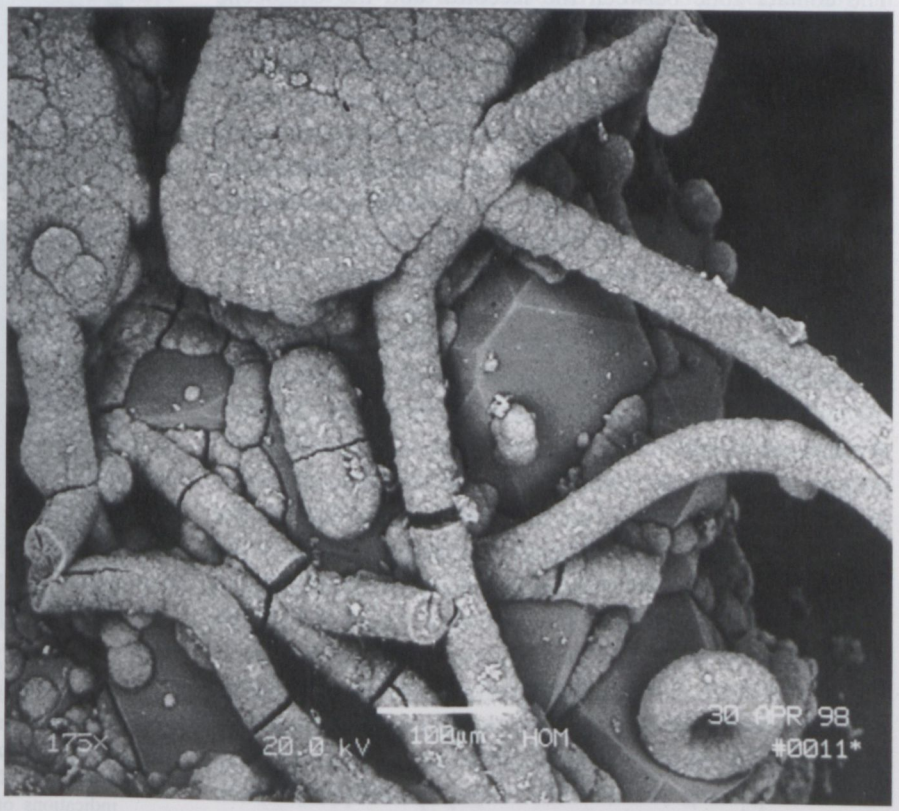

Fig. 28. Vermicular aggregates of iron saponite on chabazite (Weiszburg *et al.*, 1999). SEM micrograph (Herman Ottó Museum collection, HOM 25154; photo: Kovács, Á. – Szakáll, S.).

trioctahedral smectite, having iron as dominant cation in the octahedral position, ***"iron saponite"***. Its dominant (001) reflection moves from 14.8 Å to 16.7 Å on glycolation, while its 060 reflection is at 1.53-1.54 Å. The green variety contains also a second, subordinate phase, a yet undefined non-swelling sheet silicate. Because of that impurity the crystal chemical formula calculated from the chemical analysis $[(Ca_{0.41}Na_{0.15}K_{0.03})(Fe^{3+}_{2.29}Mg_{1.66}Fe^{2+}_{1.35}Mn_{0.13})[Si_{5.68}Al_{2.32}]O_{20}(OH)_4 \cdot nH_2O]$, should be considered only as an approximation.

Mössbauer spectroscopy demonstrated that iron occupies only octahedral positions. Although three different microenvironments are characteristic for both the green and the yellowish brown varieties, there is a major difference between them: 37% of iron is in divalent valence state in the green variety (*cf.* the chemical formula above), while 97% of iron is Fe^{3+} in the yellowish brown variety.

Iron saponite of the Csódi Hill formed by the hydrothermal alteration of mafic minerals of the hosting dacite. This is the only phase in the cavity-filling paragenesis (zeolites and different calcite generations) that hosts iron as a main component. This mineral shows remarkable similarities to iron saponite (local variety name "mauritzite") of another well known Hungarian locality, Mulató Hill, Erdőbénye, NE Hungary.

3.5 Contact metamorphism

The contact zone between the laccolith and the Oligocene Kiscell Clay has been known for long, however, for decades it had not been accessible until the new, active quarrying reached it again in 2006 on the northern side of the laccolith. The contact rock is a spotted slate (Fig. 4), with dark grey patches (0.5–1 cm) in a pale grey matrix. The sedimentary structures are sometimes preserved, in such cases, burnt plant fossils are frequent in the rock, parallel to the original bedding. The poor preservation state of these fossils does not allow any identification. Contact metamorphism is represented by ***diopside*** grains in the groundmass of the sedimentary rocks, while in the cracks ***hedenbergite*** formed. Subsequently, the rock was affected by two different hydrothermal processes that significantly overprinted the contact metamorphic paragenesis. First ***analcime*** precipitated in the cavities and around the detrital quartz grains of the sedimentary rocks, followed by potassium metasomatism, detectable in the outer zones of the feldspars. The presence of ***levyn***, an otherwise rare mineral in Hungary, was for the first time proved at Csódi Hill in the spotted slate by XPD.

Around 2008, on a crack surface of a spotted slate, beside mm size clear analcime crystals, radially arranged acicular zeolite crystals up to 1 cm length were found. Some of them were transparent, others white. X-ray powder diffraction showed natrolite structure. Qualitative SEM-EDX analyses revealed that the Si:Al ratio is approximately 3:2, which is characteristic for the natrolite series. Na:Ca ratio is varying in these fibrous or rarely massive crystals (Fig. 29), most samples are ***natrolite*** (*i.e.,* have Na as the dominant cation, but some have significant Ca substitution, too), one analysis had almost the same amount of Na and Ca (***mesolite?***), and one sample contained only Ca (***scolecite?***).

Related to the contact slates, few mm sized ***apophyllite*** crystals have been reported, too (Sándor Szakáll, personal communication).

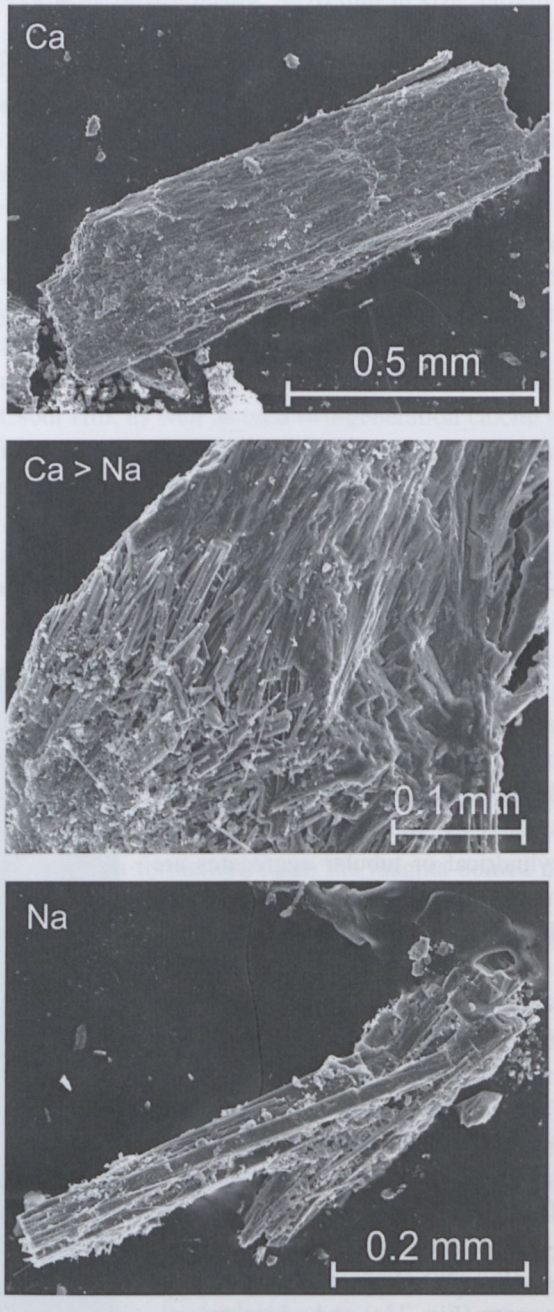

Fig. 29. SEM micrographs of the Csódi Hill acicular zeolite, grown on a crack surface of the contact spotted slate, together with analcime. The zeolite has natrolite structure (as proved by XPD), the dominant extra framework cation was most cases found to be Na (natrolite, lowermost image), but there were indications of Na-Ca mixed compositions (mesolite, middle image) and an almost pure Ca member (scolecite, uppermost image), too. Photographs and analyses taken by Melinda Jánosi.

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